D2.2: REPORT ON METHODOLOGY FOR MEASURING EACH AWI

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Abstract

aWISH project aims to develop and offer a cost-efficient solution to evaluate and improve the welfare of meat-producing livestock at a large scale, across Europe. This approach will be developed and evaluated in close collaboration with all actors involved, from primary producers up to policymakers and citizens.

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GLOSSARY OF ACRONYMS

Acronym / Term	Description
F2F	Farm-to-Fork
AW	Animal Welfare
AWI	Animal Welfare Indicators
WPs	Work packages
RFID	Radiofrequency identification
PLF	Precision livestock farming
CO_2	Carbon dioxide
NH_3	Ammonia
NGOs	Non-Governmental Organizations
FPD	Footpad dermatitis
BCO	Bacterial chondronecrosis with osteomyelitis
SSI	Self Sovereign Identity

1. EXECUTIVE SUMMARY

This report presents an overview of technologies and sensors capable of assessing pig and broiler welfare in the farming sector. The data is derived from two searches, including a systematic review and a commercial search, yielding a total of 104 technologies for pig welfare assessment and 68 technologies for broiler welfare assessment. Later a survey was sent to relevant stakeholders to ask for their opinion on knowledge gaps and the importance of validation.

For pig welfare assessment, 88 of the technologies are commercially available, while 16 are still in the prototype phase. Commercially available technologies encompass various categories, including environmental sensors (e.g., CO2, NH3, humidity, temperature), load cells, thermal cameras, cameras, infrared thermometers, flow meters, accelerometers, and acoustic sensors. Of these, 69 were developed explicitly for assessing animal welfare indicators, while 19 can be adapted for welfare assessment.

These technologies are further categorized based on their intended stage of production use, with 82 designed for on-farm applications, 4 for transportation, and 2 for slaughterhouses. At the farm level, technologies target a range of indicators such as activity level, feeding and drinking behaviour, body condition, lameness, body temperature, and environmental parameters. In the transport and slaughterhouse stages, the focus shifts to environmental conditions.

For broiler welfare assessment, 56 technologies are commercially available, and 12 are in the prototype phase. These include environmental sensors (e.g., CO2, NH3, humidity, temperature, light), load cells, thermal cameras, cameras, vibration sensors, and acoustic sensors. Of these, 43 were designed for specific animal welfare assessment, and 13 can be adapted.

Similar to pig welfare assessment, technologies are categorized by their stage of production use, with 47 intended for on-farm use, 5 for transportation, and 4 for slaughterhouses. These technologies target indicators like feeding behaviour, body condition, activity level, body lesions, gait score, environmental parameters, and more.

Both pig and broiler welfare assessment technologies are evaluated for their feasibility in slaughterhouses. Some sensors are adaptable for use in slaughterhouse resting areas, including those assessing body temperature and alarm calls using thermal cameras and acoustic sensors.

While most technologies are designed primarily for on-farm use, there is growing interest in developing technologies for slaughterhouse welfare assessment. Some prototypes are in development to assess indicators like carcass lesions, lung health, and tail length.

The report also highlights the need for adapting and training algorithms/software for the slaughterhouse environment and emphasizes the importance of transparent validation processes. Many technology providers do not share validation results, which is a concern for stakeholders in the industry. Seven pig welfare assessment products are considered validated, three already on the market and three still in development.

The results of the survey showed the technologies for assessing pig and broiler welfare, gathering 39 respondents from various fields, including academia, technology providers, and producers.

Survey participants highlighted the need to expand sensor lists for pig and broiler welfare assessment and identified additional sensors and technologies not covered in the report. Specially, they identified 19 new products for pig assessment and 9 for broilers. For pig assessment there are five different technologies (5 cameras, 8 environmental sensors, 1 flow-meter, 3 load cells, and 2 computer vision systems). Whereas in broiler there are five sorts of technologies (4 cameras, 1 acoustic sensor, 2 environmental sensors, 1 robot, and 1 using computer vision and artificial intelligence). Moreover, the participants identified seven and five prototypes' technologies for pigs and poultry, respectively.

The survey underscored the importance of transparency and external validation for technology, as concerns were raised about insufficient validation and potential bias when conducted internally. Most respondents emphasized the necessity of independent validation for credibility.

In conclusion, this report provides a comprehensive overview of available technologies for assessing pig and broiler welfare, highlighting the shift towards developing solutions for slaughterhouse use and emphasizing the importance of transparency in validation processes. This report showcases the growing interest in sensor technologies for animal welfare, along with the importance of thorough validation to ensure reliable and trustworthy results. These findings coincide with one of the main objectives of this project, which is to develop a series of technologies for assessing animal welfare indicators at slaughterhouse. It is important to note that some of the technologies found either through the systematic reviews, the commercial searches or through the survey, are prototype technologies that are being developed by some of the aWISH partners.

Disclaimer:

2. INTRODUCTION

Pig and broiler production are two of the main meat-production sectors in the European Union and worldwide. When talking about these livestock production sectors, animal welfare is very important. Since animal welfare cannot be measured directly, it needs to be assessed using other methods, such as using animal welfare indicators which allow to evaluate welfare conditions and to monitor the animals themselves.

It is well known that technology is evolving rapidly in all aspects of life and also in farm animal production. Precision livestock farming (PLF) is a set of electronic tools and methods for managing livestock that allow automatic monitoring. PLF can be used to improve production and reproduction, to assess health and welfare, and to control the impact of production on the environment. One of many advantages of PLF versus manual evaluations i.e.., human observation, is the use of objective measurements on the animals by using technological sensors, algorithms, and software.

2.1 Objective

This deliverable D2.2 “Report on methodology for measuring each animal welfare indicator (AWI)” is a part of WP2 “Animal welfare indicators and catalogue” specifically Task 2.2 “Methodology and technology for measuring each welfare indicator”.

The main objective of this deliverable is to scrutinize the existing technological methodologies for measuring animal welfare indicators in poultry and pig production, including all the stages of production. To report on the most appropriate methodology for measuring each AWI, including the available technological options, their limitations and a list of areas deserving further research.

2.2 Link to other tasks or WPs

To achieve the results of this deliverable, collaborations, and inputs from different tasks within WP2 and other WPs was necessary.

The first input needed to start working on Task 2.2 was the list of AWI of pigs and broilers, provided by Task 2.1. and explained in Deliverable 2.1, as a result of the two systematic reviews performed, one per species.

Once the technologies were identified, a survey was shared with experts identified within task 5.5. This consultation was intended to complete the information about the technology identified to assess AWIs and their validation status, with different stakeholders related to whole meat production, including the livestock sector, academia, government and NGOs, and industry and retail.

3. METHODOLOGY

Once the lists of AWI of pigs and broilers are established from D2.1 “Report on valid AWI for pigs and broilers, on farm, loading, transport and at slaughter” the next step is to scrutinize which technology and sensors, already existing on the market or still under development, can assess these AWIs.

Two sources were used to search for technologies able to assess animal welfare in pigs and broilers: (1) one was to extract the technologies used in the articles found in the systematic review performed in Task 2.1 (described in D2.1), and (2) the second source was focused on the current available technology by performing a Google search.

The lists of criteria and terms used to perform the commercial searches are given below (section 4.1) for each species. The first five pages of results (50 hits) were examined for each search criterion. All technologies capable of assessing AW were considered, regardless of whether these were currently available on the market or were still prototypes.

After the technologies were obtained, the next step was to evaluate them considering the validity, feasibility, and suitability of each one.

The criteria for accepting whether a technology is validated could be defined in different manners, as there is currently no general definition. In this case, to consider the technology as validated, the methodology explained by Gómez et al., (2021) was followed by comparing the results of the use of the technology with the gold standard through three different options:

- Against a human observer
- Comparing to another tool with a well-defined performance record
- Based on the ability to detect changes in animal behaviour or physical condition during the experiment

To determine the validation level, those technologies identified by the commercial search were checked in an additional search of the literature using the commercial name plus the name of the species. Only experiments published in scientific journals showing a good correlation (R>0.75) between the technology and the gold standard and/or providing results of accuracy, sensitivity, and specificity, were considered as validated. Results provided by the technology provider on the product website without any published results were not considered to validate a technology.

In turn, the validation could be internal (the technology is validated using the same dataset as for technology building or the origin of the validation dataset is unknown) or external (the technology is validated using a different dataset and/or under different conditions than for technology building, or by independent scientists with no relation to the provider company).

The criterion of feasibility considered whether the technology used in other stages of meat production can be implemented, adapting their use or not, to assess AWI in a slaughterhouse.

The web search to find the sensors in pig welfare was conducted between April and May 2023 while the search in broilers was done between June and July 2023.

3.1 Terms used in the commercial pig search

The criterion to perform the search using Google searcxh engine included the animal category *(pig)* plus one of the following terms related to the technology to assess AWI: (*automatic drinker OR automatic waterer), (activity sensor OR activity monitor), (RFID), (sensor), (thermal camera), (infrared thermal image), (infrared thermometer), (body-temperature sensor), (automatic weigh scale), (sorting scale), (weight camera), (body condition score sensor OR automatic body condition score), (body condition camera), (lameness sensor), (automatic lameness detection), (pressure mat OR force sensor), (automatic behaviour analyser), (image-based behaviour analyser), (automated welfare), (automated monitoring), (automatic sound analysis), (cough sensor OR cough monitor), (vocalisations analyser), (acoustic monitoring), (environment sensor), (humidity sensor), (temperature sensor), (automatic lesion detector), (visual lesions), (automatic tail detection), (automatic lung assessment), (lung visual detection), (viscera automated assessment), (stunning effectiveness detection), (automated movement detection), (body posture detector)*.

An example is given to clarify the criterion of search per each term: pig (automatic drinker OR automatic waterer).

3.2 Terms used in the commercial broiler search

The criterion to perform the search using Google tool included the animal category *(broiler)* plus one of the following terms related to the technology to assess AWI: *(automatic drinker OR automatic waterer), (RFID), (sensor), (thermal camera), (infrared thermal image), (infrared thermometer), (body-temperature sensor), (automatic weigh scale), (sorting scale), (weight camera), (body condition score sensor OR automatic body condition score), (body condition camera), (lameness sensor), (automatic lameness detection), (pressure mat OR force sensor), (automatic behaviour analyser), (image-based behaviour analyser), (automated welfare), (optical flow), (automated monitoring), (automatic sound analysis), (cough sensor OR cough monitor), (vocalisations analyser), (acoustic monitoring), (automatic lesion detector), (visual lesions), (automatic lung assessment), (lung visual detection), (viscera automated assessment), (foot pad automated assessment)*.

An example is given to clarify the criterion of search per each term: broiler (automatic drinker OR automatic waterer).

3.3 Survey content and dissemination

A survey was shared with all members of aWISH project including the Advisory Board and members of Expert Panel via email to complement the lists and check the level of validation of the found technologies. This survey was sent using the official project email to 123 email addresses:

- aWISH consortium partners: 94 contact persons from 24 partners
- Stakeholder Advisory Board: 4 members
- Expert panel Research: 14 members
- Expert panel Government & NGOs: 8 members
- Expert panel Livestock: 3 members

The survey (Annex 1) was composed of 15 questions that should take about 10 minutes to complete. The survey was split into three parts, requesting different information about (1) the respondent's background, (2) sensors and technologies to assess animal welfare, and (3) the validation status of the technology.

In the second part, two lists (one for pigs and one for broilers) were attached with several commercial sensors and some prototype technologies that may be used for animal welfare assessment. The third part was related to the technology validation.

That survey was created using the *EUSurvey* (an online survey management system for creating and publishing forms available to the public) which was completely anonymous, and no information requested could identify the participants nor link responses to specific participants.

4. RESULTS AND DISCUSSION

4.1 General explanation

All the technologies encountered after performing the two searches -the systematic review and the commercial search- are summarised in two tables, one for pigs and one for broilers. These tables can be found as an Excel file in Annex 2 for pigs, and in Annex 3 for broilers.

Each table is organized in two blocks. The left part of the table includes information related to the sensor while the right part is related to the validity of the technology. The left part contains twelve columns including information about how the sensor was found (in the commercial search or through the systematic review); if the technology was developed specifically to control/assess animal welfare or if that technology has other purpose but can be used to evaluate an animal parameter related to animal welfare; if it is currently commercialized or is still a prototype; the commercial name; the name of the technology producer company; the type of technology; the main objective of this technology; what indicator is measured by the sensor; at which stage of pig production is the sensor designed to be used; if this sensor could be used at the slaughterhouse; the website link with information about the sensor; and in the country of the company who developed the technology. The right part has five columns, including information on whether this technology is validated for assessing the corresponding animal welfare indicator; how this technology has been validated (internally or externally); what is the “gold standard” indicator used to validate the sensor; the results provided to confirm the validation (including the accuracy, sensitivity, specificity, or other results); and the source where the validation information was found.

The technologies are grouped by the different steps of meat production (farm, transport, and slaughter). Inside each step, technologies are ordered according to what AWI is measured. Each column has a filter allowing the technologies to be grouped according to different criteria.

4.2 Technologies and sensors able to assess pig welfare

A total of 104 technologies were extracted after performing the two searches, 13 from the systematic review search and the remaining 91 from the commercial search.

The first criterion to be considered is whether a technology is currently on the market, or it is still a prototype. Applying this criterion, the results can be divided into two groups: 88 technologies are available on the market, whereas 16 technologies are not available therefore still considered as prototypes.

Of the 88 **technologies commercially available**, there are *31 environmental sensors* (7 for measuring CO_2, 4 for NH_3, 1 for particle pollution, 10 for humidity, and 9 for temperature detectors), *26 load cells* (used 13 for drinkers and feeders with and without RFID, 9 for sorting scale, and 4 for force plate), *11 thermal cameras*, *10 cameras* (six of these are 3D cameras), *4 infrared thermometers*, *3 flow meters*, *1 accelerometer*, and *2 acoustic sensors* (such as microphone).

A filter allows to organise these technologies according to whether that technology was developed with the specific purpose being used on animals (e.g. individual feeder/drinker) or indirectly to assess a parameter that affects animal in the farming sector (e.g. environmental sensors to monitor the farm environment). Or, conversely, whether the technology was developed to measure another parameter but can be also used to evaluate an animal welfare issue (e.g., thermal camera to assess body temperature or inflammation) which requires a subsequent analysis of the data. In this case, 69 sensors were created specifically to assess an animal welfare issue, whereas 19 were tools capable of evaluating animal welfare despite not being deliberately built for this purpose. These 19 unspecific technologies included thermal cameras, infrared thermometers, environmental sensors, and load cells (in particular, force plates) developed to measure parameters such as temperature and environmental conditions in general, but not for a specific use on a farm or on animals. However, in practical terms, these technologies were mostly used in experimental research.

Once the technologies are established, another filter allows them to be organized according to which stage of production that technology was designed to be used for, Of the 88 resulting technologies, 82 were designed for farm use, 4 for transport and 2 for slaughterhouse.

Within each step of the production chain, technologies can be organised by indicators, finding 10 different types of technologies at the **farm level**: *accelerometers* (n=1) to assess activity level; *flow meters* (n=3) to assess drinking behaviour; *load cells* to assess feeding and drinking behaviours (n=13), body condition (n=9), and lameness (n=4); *cameras* to assess body condition (n=9) and activity level (n=1); *thermal camera* (n=11) and *infrared thermometer* (n=4) to assess body temperature; *microphone* (n=2) to assess respiratory diseases; and *gas sensor* (n=12), *humidity sensor* (n=7) and *thermometers* (n=6) to assess environment parameters. At the **transport level,** 2 types of technologies have been identified: *thermometers* (n=2) and *humidity sensors* (n=2) to assess environmental parameters. The same kind of technologies were found at the **slaughterhouse level** to assess the environmental conditions: *thermometers* (n=1) and *humidity sensors* (n=1).

Of the 16 technologies that are **still prototypes**: 9 correspond to on-farm, and 7 to slaughterhouse uses respectively. In **farm** use, 3 sorts of technologies were found: *cameras* to assess the activity level including drinking and feeding behaviour (n=1), body condition (n=3), body temperature (n=1), and tail biting detection (n=2); *load cells* to assess lameness (n=1); and *microphones* to assess respiratory disease (n=1). At the **slaughterhouse**, two kinds of technologies were found: *cameras* to assess carcass lesions such as ear (n=1), skin (n=1), and tail (n=1); viscera lesions as lungs (n=1), and tail length (n=1), and *thermal cameras* to assess the body temperature (n=1) and the killing effectiveness (n=1).

4.2.1 Feasibility of sensors at the slaughterhouse

Despite many of the technologies encountered are designed or used for on-farm welfare assessment, a column on the feasibility of applying such technologies in the slaughterhouse can be found in the table. It shows whether this technology could be used or implemented in the abattoir. Some technologies could be used to assess indicators such as drinking behaviour, body condition, body temperature, vocalisations, and lameness, which could be used in the resting area at the slaughterhouse. These sensors work using flow meters (n=3), cameras (n=9), thermal cameras (n=11), infrared thermometers (n=4), microphones (n=2), and load cells, specifically sorting scale (n=1) and force plate (n=1).

4.2.2 Commercial products specially designed to measure an animal welfare indicator

The commercial products currently on the market which have been designed to assess animal welfare indicators are included in this list. The list is organized by the animal welfare indicator assessed and for the type of technology used.

Table 1. Commercial sensors to assess feeding and drinking behaviours.

Sensor name	Provider	Sensor type		Indicator
EasySlider	Big Dutchman	Load cells	Feeder	Feeding behaviour
FaroTek	Fancom	Load cells	Feeder	
SKIOLD FE100 Mini feeder	SKIOLD	Load cells	Feeder	
SKIOLD Smart Feeder	SKIOLD	Load cells	Feeder	
Call-In Pro	Big Dutchman	Load cells	Feeder/RFID	
CallMatic Pro	Big Dutchman	Load cells	Feeder/RFID	
CallBack Pro	Big Dutchman	Load cells	Feeder/RFID	
IntelliTek sow feeding station	Fancom	Load cells	Feeder/RFID	
Accu-TEAM™	Osborne	Load cells	Feeder/RFID	
FIRE® Pig Performance Testing system	Osborne	Load cells	Feeder/RFID	
SaFIRE™ Feeder	Osborne	Load cells	Feeder/RFID	
Fidos Gestation	Roxell	Load cells	Feeder/RFID	
SKIOLD ESF	SKIOLD	Load cells	Feeder/RFID	
SKIOLD Genstar Testing Station	SKIOLD	Load cells	Feeder/RFID	
WM1 water meter	AgroLogic	Flow meter		Drinking behaviour
Water Monitoring	Fancom	Flow meter		
HOBO MicroRX	Onset	Flow meter		

Table 2. Commercial sensors to assess body condition and body temperature.

Sensor name	Provider	Sensor type		Indicator
FarmSee	FarmSee	Camera		Body condition
PigVision	Asimetrix	Camera		
WeightCheck	Big Dutchman	Camera		
OptiScan	Big Dutchman	Camera		
iDOL 65 camera	Dol sensors	Camera		
eYeGrow	Fancom	Camera		
Growth sensor	GroStat	Camera		
PigBrother	PigBrother	Camera		
Pigxcel™ ID	Smart Agritech Solution of Sweden	Camera		
TriSortPro	Big Dutchman	Load cells	Sorting scale	
CIMA Control pig	CIMA Animal Farming Equipment	Load cells	Sorting scale	
CIMA Automatic Marker	CIMA Animal Farming Equipment	Load cells	Sorting scale	
CIMA Selection Weight	CIMA Animal Farming Equipment	Load cells	Sorting scale	
Automatic animal weighing solution	Hotraco Agri's	Load cells	Sorting scale	
PigScale	PigScale	Load cells	Sorting scale	
SKIOLD Tristar	SKIOLD	Load cells	Sorting scale	
CIMA Identification	CIMA Animal Farming Equipment	Load cells	Sorting scale/RFID	
ACCU-ARM Survey Scale	Osborne	Load cells	Sorting scale/RFID	
IR TABLET 640	Digatherm	Thermal camera		Body temperature
IR TABLET 320	Digatherm	Thermal camera		
EVTSCAN thermometer	EVTSCAN	Infrared thermometer		
IRT207 Heat Seeker	General Tools	Infrared thermometer		

Table 3. Commercial sensors to assess activity level, lameness, and respiratory disease.

Sensor name	Provider	Sensor type		Indicator
SMARTBOW	Smartbow GmbH	Accelerometer		Activity level
GAITFour®	CIR Systems, Inc.	Load cells	Force plate	Lameness
Tekscan's Animal Walkway	Tekscan	Load cells	Force plate	
SoundTalks	Boehringer Ingelheim	Acoustic sensor		Respiratory disease

Table 4. Commercial sensors to assess air quality and thermal comfort.

Sensor name	Provider	Sensor type		Indicator
DOL 53	Dol sensors	NH_3 sensor		Air quality
ALIS Greenhouse Sensor	Greengage Global	NH_3 sensor		
PigData	PigBrother	NH_3 sensor		
RK300-07 NH3 Concentration Sensor	RIKA	NH_3 sensor		
CO300	AgroLogic	CO_2 sensor		
DOL 139	Dol sensors	CO_2 sensor		
CO2 sensor	Fancom	CO_2 sensor		
ALIS Greenhouse Sensor	Greengage Global	CO_2 sensor		
PigData	PigBrother	CO_2 sensor		
RK300-03A Indoor Carbon Dioxide Sensor CO2 Transmitter	RIKA	CO_2 sensor	NDIR	
SenseCAP LoRaWAN S2103	Seeed Studio	CO_2 sensor		
PigData	PigBrother	Particle pollution detector		
H-702A	AgroLogic	Humidity sensor		Thermal comfort
SoundTalks	Boehringer Ingelheim	Humidity sensor		
DOL 139	Dol sensors	Humidity sensor		
Humidity sensor	Fancom	Humidity sensor		
ALIS Greenhouse Sensor	Greengage Global	Humidity sensor		
PigData	PigBrother	Humidity sensor		
SenseCAP LoRaWAN S2103	Seeed Studio	Humidity sensor		
Temperature sensor	AgroLogic	Thermometer		
SoundTalks	Boehringer Ingelheim	Thermometer		
DOL 139	Dol sensors	Thermometer		
Temperature sensor	Fancom	Thermometer		
PigData	PigBrother	Thermometer		
SenseCAP LoRaWAN S2103	Seeed Studio	Thermometer		

4.2.3 Commercial technologies able to assess animal welfare which are not specially designed to assess animal welfare indicators

This table contains the technology whose main purpose is not designed to be used in animals, but it can be used to assess animal welfare.

Table 5. Commercial sensors to assess body temperature, lameness, and thermal comfort.

Sensor name	Provider	Sensor type		Indicator
TN418L1	Metris Instruments	Infrared thermometer		Body temperature
YM-558D	Tebru	Infrared thermometer		
FLIR E8-XT	FLIR	Thermal camera		
FLIR A300	FLIR	Thermal camera		
FLIR One Pro LT	FLIR	Thermal camera		
PT850	Guide Sensmart	Thermal camera		
ATS300	InfiRay	Thermal camera		
M600	InfiRay	Thermal camera		
TR256C	Mileseey	Thermal camera		
TR256B	Mileseey	Thermal camera		
X640D	Yoseen Infrared	Thermal camera		
Footscan® 3D Gait Scientific	Materialise	Load cells	Force plate	Lameness
Pressure Mat Dev kit 1.8	Sensing Tex	Load cells	Force plate	
HOBO U23-001 Pro v2	Onset	Humidity sensor		Thermal comfort
iButton DS1923 Hygrochron	Maxim Integrated Products	Humidity sensor		
HMP60	Vaisala	Humidity sensor		
iButton DS1921H Thermochron	Maxim Integrated Products	Thermometer		
HOBO U23-001 Pro v2	Onset	Thermometer		
HMP60	Vaisala	Thermometer		

4.2.4 Technology not currently commercially available - prototypes

This section includes those technologies that are not currently on the market but are currently still a prototype at different TRL. Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the development phase.

Table 6. Prototype sensors still in development.

Sensor name	**Provider**	**Sensor type**		**Indicator**	**TRL***
Dilepix solution	Dilepix	Camera		Activity level	3-4
Embedded vision prototype	Lemberg Solutions	Camera		Body condition	3
WUGGL One	WUGGL	Camera			9
Weight-Detect TM	PLF Agritech Europe	Camera			7
WUGGL One	WUGGL	Camera		Body temperature	9
SowSIS	ILVO + UGent	Load cells	Force plate	Lameness	4-5
TAIL	Dilepix	Camera		Tail biting	6-7
TailTech	Innovent Technology Ltd	Camera		Tail position (tail biting)	5
ALIS Grunty Sensor	Greengage Global	Acoustic sensor		Vocalisations	?
Bleeding control	CLK GmbH	Thermal camera		Killing effectiveness	9
ADAL	Farm4Trade	Camera	Robot	Lungs lesions	8
PigInspector®	CLK GmbH	Camera	With a light sensor	Ear lesions	9
PigInspector®	CLK GmbH	Camera	With a light sensor	Skin lesions	4
PigInspector®	CLK GmbH	Camera	With a light sensor	Tail length	3-4
TailCam	PigWatch	Camera			6-7
PigInspector®	CLK GmbH	Camera	With a light sensor	Tail lesions	9
STREMODO	FBN	Microphone		Vocalisations	4

*Disclaimer: The TRL is not directly stated by the provider/researcher, but that is estimated based on the information provided on the provider websites or in papers published, following the description of TRL.

4.3 Technologies and sensors able to assess broiler welfare

A total of 68 technologies were extracted after performing the two searches, 18 from the systematic review search and the remaining 50 from the commercial search.

The first criterion to be considered is whether the technology is currently on the market, or is still a prototype. Applying this criterion, the results can be divided into two groups: 56 technologies are available to be purchased, and 12 technologies are not available.

Of the 56 **technologies commercially available**, there are 22 *environmental sensors* (5 for measuring CO_2, 6 for NH_3, 5 for humidity, 1 for light, and 5 for temperature detectors), *18 load cells* (1 used for feeders and 17 for sorting scale), *2 thermal cameras*, *12 cameras* (including 3D camera), *1 vibration sensor*, and *1 acoustic sensor* (such as a microphone).

A filter allows to organise these technologies according to whether the technology was developed with the specific purpose of being used on animals (e.g. individual feeder/drinker) or indirectly to assess a parameter that affects animal in the farming sector (e.g. environmental sensors to monitor the farm environment). Or, conversely, whether the technology was developed to measure another parameter but can be also used to evaluate an animal welfare issue (e.g. thermal camera to assess body temperature or inflammation) which requires a subsequent analysis of the data. In this case, 43 sensors were created specifically to assess an animal welfare issue, whereas 13 were tools capable of evaluating animal welfare despite not being deliberately built for this purpose. These 13 unspecific technologies included thermal cameras, cameras, and environmental sensors, developed to measure parameters such as temperature and environmental conditions in general, but not for a specific use on a farm or on animals. In practice, most of these technologies were used in experimental research.

Once the technologies are established, another filter allows them to be organized according to which stage of production that technology was designed to be used for. Of the 56 resulting technologies, 47 were designed for farm use, 5 for transport and 4 for slaughterhouse.

In addition, within each step of the production chain, technologies can be organised by indicators, finding 8 different types of technologies at the **farm level**: *load cells* to assess feeding behaviours (n=1) and body condition (n=17); *cameras* to assess body condition (n=1), activity level and behaviour patterns (n=4), body lesions (n=2) and gait score (n=1); *infrared camera* to assess body temperature (n=1), and cluster of birds (n=1); *acoustic sensor* (n=1) to assess alarm calls; and *gases* (n=9), *humidity sensor* (n=4), *thermometers* (n=4) and *light control* (n=1) to assess environment parameters. At **transport,** it has been identified 4 types of technologies: *thermometer* (n=1)*, humidity* (n=1), *vibration* (n=1), and *gas sensors* (n=2) to assess environmental parameters. At the **slaughterhouse** we found one type of sensor, an *image analysis sensor* to assess the body measurements (n=1), and body lesions (n=3).

Among the technologies that are **still prototypes** (n=12): 10 correspond to on-farm, and 2 to slaughterhouse uses. In **farm** use, 4 sorts of technologies were found: *cameras* to assess the activity level (n=1), body temperature (n=1), and foot pad dermatitis and hock prediction (n=1); *near-infrared camera* to assess distribution (n=1); and *microphones* to assess vocalizations (n=2), and CO_2 levels detection (n=1), sneezing detection (n=1), and body weight checking (n=1); and *RFID* to assess activity level (n=1). While at the **slaughterhouse**, one kind of technology was found: *cameras* to assess carcass lesions (n=1), viscera lesions as lungs (n=1), and killing effectiveness (n=1).

4.3.1 Feasibility of sensors at the slaughterhouse

As many of the technologies encountered are designed or used for on-farm welfare assessment, a column on the feasibility of applying such technologies in the slaughterhouse can be found in the table. It means whether this technology could be used or at least can be implemented in the abattoir. Two products could be used to assess body temperature and alarm calls in the resting area at the slaughterhouse. These sensors work mainly using thermal cameras (n=1), and acoustic sensors as microphone (n=1).

4.3.2 Commercial products specially designed to measure animal welfare

The commercial products currently on the market which have been designed to assess animal welfare are included in this list. The list is organized by animal welfare indicator assessed and for the type of technology used.

Table 7. Commercial sensors to assess body weight, feeding behaviour, activity, and alarms calls.

Sensor name	Provider	Sensor type	Indicator
BroilerZoom	Animoni	Camera	Body weight
DOL 94 poultry scale	Skov	Scale	
DOL 98S poultry scale	Skov	Scale	
APWS	AgroMax	Scale	
CVDI-P	CTI control	Scale	
BAT2 scales	veit.cz	Scale	
Weltech weighing scale	Weltech	Scale	
DWS-4-ZW	Hotraco Agri	Scale	
SKU: 003-OPT-83-000	Ruby 360	Scale	
GE-OPTIKIT	Monitrol	Scale	
CHORE-TIME Bird scale for broilers	CHORE TIME	Scale	
RSC-2SE Poultry Scale Center	Munters	Scale	
PS1 - bird scale	Dacs	Scale	
Opticon Broiler Chicken Scales	AAS	Scale	
HMP2	All Scales Europe	Scale	
Lumina 47	Fancom BV	Scale	
Incas Compact	Big Dutchman	Scale	
Swing 20	Big Dutchman	Scale	
ChickTrack	FarmWorx	Camera	Activity
iDOL 29 sensor	Big Dutchman	Load cell	Feed level
ALIS Cluster sensor	Greengage	Thermal camera	Clustering
ALIS Chirpy sensor	Greengage	Acoustic sensor	Alarm calls

Table 8. Commercial sensors to assess air quality and environment comfort.

Sensor name	Provider	Sensor type	Indicator
Alis greenhouse sensor	Greengage	CO_2 sensor	Air quality
DOL 139	DOL sensors	CO_2 sensor	
Transport Genie	Transport Genie Ltd	CO_2 sensor	
Alis greenhouse sensor	Greengage	NH_3 sensor	
DOL 53	DOL sensors	NH_3 sensor	
Transport Genie	Transport Genie Ltd	NH_3 sensor	
ALIS Ambient Sensor	Greengage	Light sensor	Environment comfort
DOL 139	DOL sensors	Thermometer	
ALIS Ambient Sensor	Greengage	Thermometer	
Alis greenhouse sensor	Greengage	Humidity sensor	
DOL 139	DOL sensors	Humidity sensor	
Transport Genie	Transport Genie Ltd	Vibration	
Transport Genie	Transport Genie Ltd	Thermometer	
Transport Genie	Transport Genie Ltd	Humidity sensor	

Table 9. Commercial sensors to assess body measurements and body lesions.

Sensor name	Provider	Sensor type	Indicator
CLK-Rendite-System	CLK Gmbh	Camera	Body measurements
Meyn Foot Pad Inspection	Meyn Inc	Camera	Foot pad dermatitis
ChickenCheck	CLK Gmbh	Camera	
eyeNamic system	Fancom BV	Camera	
eyeNamic system	Fancom BV	Camera	Hock burns
IRIS	Marel	Camera	Wounds
eyeNamic system	Fancom BV	Camera	Gait score

4.3.3 Commercial technologies able to assess animal welfare which are not specially designed to assess animal welfare

That table contains the technology whose main purpose is not designed to be used in animals, but it can be used to assess animal welfare.

Table 10. Commercial sensors to assess behaviour patterns, body temperature, air quality, and thermal comfort.

Sensor name	Provider	Sensor type	Indicator
Qualisys Track Manager	Qualisys	Camera	Stride length
Qualisys Track Manager	Qualisys	Camera	Acceleration
Qualisys Track Manager	Qualisys	Camera	Distance
FlirOne; Lepton	FLIR systems	Thermal camera	Body temperature
BW SOLO AMMONIA DETECTOR	Honeywell	NH_3 sensor	Air quality
RS-NH3-*-2-*	Renkeer	NH_3 sensor	
Aranet NH3 sensor kit	Aranet	NH_3 sensor	
Aranet CO2 and Temperature sensor	Aranet	CO_2 sensor	
RS-CO2*-*-2	Renkeer	CO_2 sensor	
Aranet CO2 and Temperature sensor	Aranet	Air temperature	Environment comfort
Aranet T/RH IP67 sensor	Aranet	Temperature	
Aranet T/RH IP67 sensor	Aranet	Humidity sensor	
RS-WS-*-2D	Renkeer	Humidity sensor	

4.3.4 Technology not currently commercial - prototypes

This section includes those technologies that are not currently on the market or are in commercial use because remain such as a prototype at different TRL. Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program.

Table 11. Prototype sensors still in development.

Sensor name	Provider	Sensor type	Indicator	TRL*
HF RFID reader DSLR1000	Dorset Identification B.V.	RFID; RFID reader	Activity	8
SOMO	SoundTalks	Microphone	Body weight	8
HD-B-1001	Youanhong Technology Limited Company	Microphone	Sound	6
SM080TIP camera	Somo Energy & Technology Co., Ltd	Camera	Body temperature	7
PRO-1080MSFB	Swann Communications	Camera	Distribution	7
Web cameras c120	Anders Electronics	Camera	FPD & hock burn	5
acA2040-25gmNIR CMV400	Basler AG	Camera	Distribution	8
Superlux ECM999	Superlux	Camera	Sound	7
Zoom H4n Pro Portable Recorder	Zoom electgronics	Camera	Sound	8
VetInspector	IHFood	Camera	Lesions	8
SOMO	SoundTalks	Camera	Sneezing	8
Microvision EM130C	Microvision	Camera	Body posture	8

*Disclaimer: The TRL is not directly stated by the provider/researcher, but it was estimated from the information provided on the manufacturer's website or in papers published following the description of TRL

4.4 Results extracted from the survey

After sharing the survey with 123 members, 39 responses were received. The results extracted from the survey are divided in three sections: participants background, sensor technologies, and validation.

Regarding the background of the participants, the main field of work was academia/research (n=22), the second was technology providers (n=5) followed by producers (n=3), and other industries including NGOs (n=2), management and engineering (n=1), veterinarian (n=1), government (n=1), project management (n=1), agriculture (n=1), and competent authority (n=1). Going deeper into the field of expertise of the participants, the majority were animal behaviour/welfare (n=20), followed by animal production (n=6), sensor provider (n=3), sensor developer (n=2), PLF research including validation (n=2), animal health (n=1), plant protection (n=1), management and engineering (n=1), agriculture economics (n=1), and project management (n=1).
Most participants (n=21) have more than 10 years of experience, followed by a group (n=10) where people have between 5 and 10 years, another group (n=5) with an experience between 1 and 5 years, and a small group (n=3) with less than one year of experience. The distribution of the participants according to country was as follows: Germany (n=6), Belgium (n=6), Spain (n=5), Austria (n=4), France (n=3), United Kingdom (n=3), Poland (n=2), The Netherlands (n=2), Serbia (n=2), Denmark (n=1), North Macedonia (n=1), and Israel (n=1). Three participants did not indicate the country. Of all participants, 17 people work mainly in pigs and 9 in broilers, however, there is another group of 11 people working in both species, one participant works in both pigs and cattle, and another one works mainly with plants. Summarising this first part, most of the participants belong to the academic/research field and the main species studied was pigs.

After sharing the two lists of sensors encountered in pigs and in broilers with the participants, first outcome of the respondents was that the list should include the following animal welfare indicators in pigs: facial expressions to assess pain, manipulation of environment enrichment, play behaviour, emotional state, heart and respiratory rate, stress, tear staining, hernias, bursitis, human and animal interactions, and piglet crushing in farm level. The use of accelerometers to monitor animals in trucks was also commented. While in the broiler, the missed indicators were drinking behaviour, behavioural changes, resting, heart rate, breast myopathies, BCO identification, and breathing pattern. It should be noted that the absence of these indicators in the lists is mainly due to not finding sensors able to automatically assess these indicators.

A list of sensors or technologies currently on the market in broilers (Table 12) and one in pigs (Table 13) that were not identified by our review and desk research was mentioned by respondents.

Table 12. List of technologies used in broilers provided by the survey participants.

Sensor	Technology	Provider	Purpose
Optical Flow	Camera	University of Oxford	Analyse flow patterns
ChickenBoy	Camera	Faromatics/BigDutchman	Detection and mapping of birds' distribution
ChickenBoy	Acoustic sensor	Faromatics/BigDutchman	Measure noise levels
ChickenBoy	Environmental sensors	Faromatics/BigDutchman	Temperature, humidity, and gas levels
FLOX.ai	Artificial Intelligence	FLOX.ai	Better welfare, productivity, and sustainability
XO	Camera	Octopus Poultry Robotics	Detection, counting and localization of dead chickens
T-MOOV	Robot	Octopus Poultry Robotics	Keep birds moving and reduce the count of floor eggs

XO	Environmental sensors	Octopus Poultry Robotics	Temperature, humidity, and gas levels
Pondus	Camera	Pondus XYZ	Body weight measurements

Table 13. List of technologies used in pigs provided by the survey participants.

Sensor	**Technology**	**Provider**	**Purpose**
CET'Automatique	Camera	Wel2be	Automatic control of pig unconsciousness at slaughter
ArtificialVet®	Camera	Company Mind	Assess animal welfare indicators and slaughter
AI4Animals	Camera	Deloitte	Uses artificial intelligence to monitor animal handling in slaughterhouses
Arad Sonata Water Meter	Flow-meter	Diversified	Highly accurate ultrasonic water meter
DOL 119	Environmental sensors	DOL sensors	CO2 levels measurements
DOL 114	Environmental sensors	DOL sensors	Temperature and humidity levels
Healthy Climate Monitor	Camera	Healthy Climate Solutions	Behaviour the animals in real-time
Healthy Climate Monitor	Environmental sensors	Healthy Climate Solutions	Temperature, humidity and gases levels
Krestel DROP D3 sensor	Environmental sensors	Kestrel	Temperature, humidity and pressure data logger
Nedap Velos PPT stations	Load-cells	Nedap Livestock Management	Feed behaviour and daily weight measurement
Nedap Electronic Sow Feeding	Load-cells	Nedap Livestock Management	Feeding individual sows in group
Copeeks	Camera	Peek Analytics	Position and activity level of the animals
Copeeks	Environmental sensors	Peek Analytics	Temperature, humidity and gas levels
Enviro-Detects™	Environmental sensors	PLF Agritech	Temperature, humidity and gas levels
Argus	Computer vision	{SAAS} & TUDelft	Analysis of animal behaviour, consciousness after stunning, and equipment usage.
Serket	Computer vision	Serket	Behaviour monitoring
SmartSpot	Environmental sensors	Hopu Smart Cities	
Nedap ProSense	Load cells + RFID	Nedap	Measures and records individual weights, feed intake and feed conversion ratio in pigs allowed in group
i-Sensor	Environmental sensors	Exafan	Temperature, humidity and gases levels

Three companies with their technologies located in Brazil were suggested by one participant, but no information on website could be found:

- *F&S Consulting*: broiler electrical stunning without live bird inversion. Assure welfare of the birds within the slaughtering line in accordance with the EU regulation #1099, OIE and ECC.
- *Trinovati*: non-invasive automatic system for integrated monitoring in broiler production (AI). Illnesses and welfare prediction based on the production data monitoring, and weight prediction for slaughter. Use of different sensors capturing environmental temperature and humidity, temperature of the bed and of the water, weight of the birds, internal and external pressure, light intensity, and carbon dioxide levels.
- *3D Pig*: non-invasive automatic system for integrated monitoring in pig production (AI). Illnesses prediction based on behaviour and welfare monitoring by thermal comfort and monitoring of zootechnical performance. Use of 3D and thermal camera, environmental sensors, mass sensor and thermal comfort.

In addition, some indicators and technologies in **prototype** phase were extracted from the survey results. In pigs, currently different indicators are still being studied using cameras and artificial intelligence such as tear staining evaluation, the state of unconsciousness by checking the corneal reflex or rhythmic respiration in hanging pigs after stunning, the verification of the absence of signs of life before the processing procedure, the detection of pig tail lesions at slaughterhouse level. On-farm, facial expressions, scoring the movement of the gilt observing the body joints, and piglet crushing prevention using cameras, and body temperature to anticipate emotion using thermal cameras, and automatic behaviour recognition by computer vision are being studied. In broilers, the assessment of the state of consciousness after water-bath and gas stunning, a camera system for inspection of catch damage and a camera system for identifying various diseases as ascites and deep dermatitis are being studied at the slaughterhouse level, whereas on the farm level thermal sensors and feather cover and cleanliness are being studied.

According to respondents' feedback, in **pig farming**, there is a clear interest in technologies such as image-based or video analysis able to assess the individual level of welfare such as activity, lethargy, feeding and drinking behaviour, excretory behaviour (exhaled or excreted metabolic products) to detect diseases, problems linked to behaviour such as tail biting and aggression, or the development of technologies capable of assessing positive animal welfare. One concern regarding farrowing sows was highlighted, which was the need to develop a system based on thermal cameras or cameras to assess pain and difficulties in farrowing, such as the interval between piglets' expulsion. Another emerging idea was the utilization of an AI to interpret sensor data and make predictions on growth and weight gain depending on conditions. An ideal scenario would be to develop a technology using AI to assess animal behaviour at the individual level by evaluating the "whole body" through a combination of various indicators and technologies, including RFID, cameras, sound sensors, and wavelength-capturing devices. In the context of **transportation,** there was an interest in monitoring the behaviour and postures using cameras. At the **slaughter** level, there is a highlighted interest in ensuring stunning effectiveness, lung conditions assessment, evaluation of tail biting injuries and tail length at a commercial scale, and automatic detection of bruises and fractures by a camera. Also, a respondent suggested to take advantage of installing sensors for capturing the emissions at slaughterhouse level.

For **poultry farms**, participants were focused on the need to develop more technologies able to evaluate lameness and hock burns and suggested using RFID technology to monitor activity levels. Another technology mentioned was acoustic analysis to monitor activity and health problems such as respiratory disease. Another point of interest was the suggestion to use a combination of single indicators to capture the behaviour and welfare of animals and, if possible, integrate all this information into an App. It was also suggested to create a sensor technology that would allow early detection of animals prone to cannibalism.

A note commented in general to complement all the previous suggestions was the need for more investigation into the Self-Sovereign Identity (SSI) approach which gives people or organizations full control over their data and allows them to bring their own identity.

Regarding the **feasibility** of using technologies that are commonly used in farm, some opinions were provided by the participants. In pigs, there is a general and frequent interest in evaluating the killing effectiveness studying the bleeding process using thermal imaging, the use of cameras to assess behaviour at the lairage and the stunning box, developing sensors for testing the corneal reflex or the nose prick, and the use of microphones to assess vocalizations or noise in general (including signs of respiratory disease) for example using technologies already developed like SoundTalks. The use of cameras to also detect lesions such as tail biting, ear and skin lesions and evaluate the lungs. Developing a system to assess tail length in combination with tail lesions able to operate on a commercial scale. Use cameras to measure body condition, and load cells to assess body condition and lameness. Use thermal cameras or infrared thermometers to evaluate body temperature in lairage. In broilers, the list is shorter than in pigs, and according to the participants, it makes sense to assess indicators that can be surely assigned to a specific phase, such as footpad dermatitis (FPD) or hock burn, since other types of lesions there is the problem that these could have occurred during housing or transport and lairage. Technologies such as microphones and acoustic sensors are useful to assess vocalizations, and cameras and/or load cells to evaluate body weight. In transport, behaviour patterns and detection of abnormal vocalizations could be studied.

As far as the adaptation of those technologies at the slaughterhouse level the most important concern to consider is the limitation due to the line speed and the facilities, so technologies should be trained (including setting up and calibrating the systems) and well-positioned to measure with a certain level of accuracy what they intend to measure and provide reliable data. Furthermore, it must be considered that the slaughterhouse environment is totally different from the farm one. The former one is usually hot and damp with many mechanic sounds whereas the latter one is usually very dusty, for that reason farm technologies must be adapted to be usable in other contexts working in high humidity, temperatures, and noise levels such as abattoir. Moreover, technologies often require new developments to assess parameters on carcasses instead of live animals and link the outputs with a specific batch or farm. In poultry, respondents commented that technologies should be adapted to identify stressful behaviours during transport and layover at the abattoir. Lastly, highlight the importance of one participant's comment saying that validation to use technology designed for the farm level at the slaughterhouse is needed.

The last section of the survey basically deals with the technology validation level. The survey showed a strong concern that validation should be transparent. When talking about the validation extracted from the papers, they marked that it is sometimes based on a small number of farms (often only one) and stressed the importance of considering the variability of the environment on different farms. Another aspect to point out is how much reliable the gold standard is for validating a technology. Regarding the correlation coefficient between technology and the gold standard, two participants suggested that $r>0.85$ indicates a strong, positive, and linear relationship. However, when it deals with welfare, a higher correlation is preferable, and the sample size should be considered in the statistical analysis.

A 72% of participants have the same concern that it is not sufficient to commercialize products without proving the results of validation. The reasons are listed below as quotes:

- “Validation should be provided but it will be still a site-specific issue unless the slaughterhouse is built completely new and sensor technology is implemented in the planning phase.”
- “The products must be validated prior to use.”

- "The client needs transparency to confirm the robustness of the output data, moreover, this validation must from my point of view be done by an independent organization to guarantee its objectivity."
- "A proof of validation is necessary to ensure that the sensors are actually working and can assess the indicators."
- "Many products rely on a placebo effect to give them some positive results."
- "That is the reason why the implementation of technologies is somehow limited. A proper validation should back up any sensor so when farmers evaluate the cost vs benefit dilemma, they have proper information for decision-making."
- "It is not enough due to the results of validation are very important."
- "Validation can be an important criterion to be sure that the technique works in all scenarios."
- "Validation results would be very good to add."
- "Scientific validation is always needed."
- "There is too much focus on commercial gain and not enough evidence to guarantee the farmer (buyer) that it works. Especially when considering system recommendations for medication (such as after coughing) the technology needs to be precise."
- "Results should be provided. However, how in-depth could be open for discussion because it is understandable providers do not want to share all their details."
- "Validation results would provide transparency but could implicate the company negatively from a copyright perspective."
- "The providers should, at least, provide data showing that the technology is fit for its purpose i.e. that it can provide a practically relevant result."
- "Some degree of validation would be desirable."

As to whether external validation (i.e., not by the industry/company which developed the technology) is necessary to validate the technology, 85% of participants responded positively and the reasons are explained below:

- "An internal validation can never be objective".
- "An external validation (by ethologic studies office for example) provides an essential scientific credibility.
- As quality control, the assessor should be neutral".
- "External validation will mean that standards are defined and the compliance of the commercial product to the standards. This will allow to compare similar systems from different providers".
- "Only after validation the sensor and program give use data which is valid".
- "It would be better to have a gold standard for this technology".
- "Ideally technologies should be externally validated, but that seems complicated to implement".
- "External validation is necessary for transparency and objectivity".
- "There is variation in management practices".
- "It is always more trustable for a technology to be validated by a third party without any conflict of interest and it helps to improve the technology by identifying opportunities for improvement".
- "If not external validation, then it is also nice to have a quality control scheme to ensure the internal validation process".
- "When somebody decides to use it, it needs to be validated. It is no good scientific practice to use a method without knowing about it. Especially when dealing with living animals".
- "Because it's important always an independent validation to ensure the indicators are well detected".
- "At least, a scientific validation would be useful to give strength to the technology".
- "If internally validated, could be biased or limited by own knowledge and expertise".
- "Regarding the use of these technologies as animal welfare assessment tools, an external validation would be necessary to ensure that the focus is on animal welfare and that the sensors are actually working".

- "It should be in the company's interest to have it externally validated to prove the efficacy of the product/system. Unfortunately, some companies ask universities to test their product, and when the results are inconclusive or even negative for the product, they will still advertise it as having been 'Tested by the University of ###'. Which is of course not untrue".
- "It is ideally, but practically difficult to do".
- "It is safer for them to be externally validated".
- "The customer wants a system that works according to their requirements".
- "Testing is the only way to prove usability".
- "Neutral validation should be performed".
- "If the commercial companies validated their own product is not trustworthy".
- "It is the best way to prove objectively that the technology works".
- "It allows transparency for the customer and the end-users, especially when used in monitoring schemes".
- "Further proof would be necessary".
- "To fully trust data from a sensor, external validation is a must".

Four participants said that external validation is not needed. One mentioned that technology can be validated by a company if scientific methods are used and if it is performed by experts in the field. The validation process must be clear and reproducible and some companies have special departments for research and product development, where (scientific) experts are working. If not, the technology must be validated by external experts. Another participant pointed out that internal validation is the key saying that the external one is a surplus but not a necessity. But, if the method of validation and the results are published, these can be consulted and the buyer should be able to determine, whether the product was worth the effort.

4.5 Status of the technology validation

Considering the validation criteria used in this review, only seven products have been considered validated to assess pig welfare (Table 14) and 10 to assess welfare in broilers (Table 15). Most technologies used to build the products are cameras (n=4); accelerometer (n=1); load cell, specifically force plate (n=1); microphone (n=1); and thermal camera (n=1).

Table 14. Validated technological products to assess pig welfare.

Sensor name	Provider	Sensor type	Indicator
SMARTBOW	Smartbow GmbH	Accelerometer (ear tag)	Activity level
iDOL 65 camera	Dol sensors	Camera	Body condition
FLIR One Pro LT	FLIR	Thermal camera	Body temperature
SowSIS	ILVO + UGent	Load cells (Force plate)	Lameness
TailTech	Innovent Technology Ltd	Camera	Tail biting (tail position)
STREMODO	FBN	Microphone	Vocalisations
PigInspector®	CLK GmbH	Camera	Ear lesions
PigInspector®	CLK GmbH	Camera	Tail lesions

SMARTBOW uses accelerometers to monitor the activity. Although it is designed to be used in cows, the study conducted by Ozak et al., 2022, compared the accelerometer with human labelling to determine the activity of the sow resulting in a correlation of 82%.

iDOL 65 camera was validated by comparing the results of the body weight estimation with the manual weight in the study performed by Franchi et al., 2022 which the correlation was R>0.96 at both individual and pen levels.

FLIR One Pro LT is a regular thermal camera, not exactly designed for animal use, but the study conducted by Küster et al., 2023 compared the rectal temperature with the results of the camera helped, by the Otsu algorithm, to estimate the body temperature with a correlation of 0.774.

SowSIS is a device not commercialised and is based on load cells specifically four force plates built into an electronic feeder to measure the output of each leg to estimate and validate lameness. This is a study performed by Briene et al., 2021 where they compared the level of lameness between the results provided by the device and the visual gait score recorded by a human observer with a 78.5% sensitivity, 81.4% specificity, 80.7% accuracy, 57.4% lame predictive value and 92.2% non-lame predictive value.

TailTech is the result of a project that is currently not commercially available. It is a camera linked to an algorithm able to predict and detect tail-biting before an onset based on tail position. This technology was compared with the tail position assessed by human observation in the study performed by D'Eath et al., 2018 where the results showed a 73.9% accuracy, 88.4% sensitivity, and 66.8% specificity in the automated detection of tail position.

STREMODO is an acoustic sensor able to assess the stress screams of domestic pigs which is not commercially available. The study performed by Schön et al., 2004 compared the vocalizations recorded automatically with the human labelling, which found a correlation of 0.84.

PigInspector® is a system based on cameras still in development to assess the skin lesions in the carcass during the slaughter process. Blömke et al., 2020 compared the system with human observations in ears and tails and they found 95.4%, 77%, and 96.5% of accuracy, sensitivity, and specificity respectively in ear lesions and 99.5%, 77.8%, and 99.7% in tail lesions.

As for the pigs comparatively few of the methods have been validated, in the case of the broilers 15 measures have been externally validated, of these 10 have reached the criterion used in this review.

Table 15. Validated technological products to assess broilers welfare.

Sensor name	**Provider**	**Sensor type**	**Indicator**
HF RFID reader DSLR1000	Dorset Identification B.V.	RFID; RFID reader	Activity
BroilerZoom	Animoni	Camera	Body weight
SOMO	SoundTalks	Microphone	Body weight
HD-B-1001	Youanhong Technology	Microphone	Vocalisations
FlirOne; Lepton	FLIR systems	Thermal camera	Body temperature
Meyn Foot Pad Inspection	Meyn Inc	Camera	Footpad dermatitis
eyeNamic	Fancom BV	Camera	Gait score

Zoom H4n	Zoom electronics	Microphone	Distress vocalisations
Somo sound talks	Somo soundtalks	Microphone	Sneezing
Microvision EM130C	Microvision	Camera	Body posture

HF RFID reader DSLR1000 uses RFID to assess the walking distance of individual birds in flock. In the study (van der Sluis et al., 2020), that used a low number of birds (40) the result of the system was highly accurate, matching the location of the individual bird compared to a video recording of the birds with an accuracy of 99%. No studies on the system in a commercial setting was found.

BroilerZoom was tested under commercial conditions. A traditional platform weigher was used to estimate the reference weights. An average relative mean error of 8% between the predicted and the weights and the reference weights was achieved on a separate test set with 83 broilers (Mortensen et al., 2016). The errors were generally larger in the end of the rearing period as the broiler density increased. The main advantage of the system is that also birds that do not want to step up on a scale because of lameness, can be assessed.

SOMO was used to study the correlation between body size and pitch in broilers. The study performed by Fontana et al, 2017 was done under commercial conditions, using eight rotations, in two different farms. There was a significant difference between the expected and observed body size (P=0.01) for the last week, week 6. For the previous weeks there was a very good correlation between expected and observed values (R2=0.93, P<0.001).

HD-B-1001 together with an algorithm was developed to detect coughing, snoring and interfering sounds. When Liu et al., 2020 compared the results from recordings in a commercial setting, with those of a human observer the sounds could be correctly classified in 94% of the cases.

FlirOne; Lepton, using a thermal camera it was possible to detect changes in body temperature in broilers. When Bloch et al., 2020 compared the results with those obtained by loggers implanted in the body cavity of the broilers the difference was only ±0.27 C. The authors of the study suggest that the method may be used to check climate control using the body temperature of the broilers.

Meyn Foot Pad Inspection was developed to automatically assess foot pad dermatitis. The system was tested both on farm and at slaughter. The initial scores were not very good when compared to those of a human assessor (r=0.54 and 0.59). When large and obvious errors (e.g. foot pads not assessed at all) were removed, the scores reached r=0.69 and 0.74. It is clear that more work needs to be done before the system can be thought of as being completely validated (Vanderhasselt et al., 2012).

eyeNamic was used to assess activity and its relation to gait score, foot pad lesions and hock burns. The study was carried out in a commercial setting by Hertem et al., 2018. While the prediction was poor for foot pad lesions and hock burns, the relation to gait scores was good, with a correlation of up to 0.7 between the activity recorded and the gait score.

Zoom H4n, Mao et al., 2022 in this study a comparison was made between an algorithm and humans for selected recordings obtained under commercial conditions, both of distress calls and of natural sounds. The method used obtained an accuracy of 95%. The selection of the sound recordings used in the study will however clearly influence these results.

Somo Sound Talks, an algorithm was developed to detect sneezing in broilers by Carpentier et al., 2019. When tested with a group of 51 chickens a precision of 88% was obtained.

Microvision EM130C is used to assess the level of stunning in broilers. In a study conducted by Ye et al., 2020, three levels of stunning were defined as: Insufficiently stunned broilers flutter or raise their heads. The moderately stunned broilers temporarily lose consciousness and appear to be still. Excessively stunned broilers have completely lost consciousness or are dead, their heads hang loose and their wings are open. After training, the method had an accuracy of 98% when tested at commercial speed.

5. CONCLUSIONS

It is worth to mention first the difference between the number of sensors used in pig and broiler production. In pigs 107 commercial sensors and 23 prototypes were found whereas in broilers this number was drastically reduced to 65 are commercially available, and 17 are still prototyping.

The most part of the technologies are designed mainly for on-farm use in both species. However, there is a high interest in studying and developing new technologies able to assess welfare at slaughterhouse use. It is important to emphasize that some of these prototyping technologies are being developed by aWISH partners. For example, in pigs, sensors using cameras and artificial intelligence to assess tear staining or the level of animal unconsciousness' after stunning, or sensors to assess the level of injury and the length of the tails are being developed. In broiler, they are developing technologies that use computer vision to assess the level of consciousness after stunning or technologies able to assess lesions on carcass such as catch damage, footpad, or hock burns.

Regarding the feasibility of the sensors or technologies used normally at the farm level, should be adapted and the algorithms/software need to be trained to work in a different environment taking into account the limitations of the slaughterhouse.

Regarding the validation of the technology, providers do not tend to share the results of sensor validation. Most providers sell the products on their web pages ensuring that the product is validated and giving characteristics as the percentage of the accuracy, without providing the results of such validation. Survey participants have shown a clear and strong concern for the need to provide results of the validation process and that validation should be external for the sake of transparency.

Table 16 shows the seven products used in pigs to assess welfare considered, under our criterion, validated. At present, three are currently on the market whereas the other three are still under development. These prototypes offer interesting results with good correlations between technology and the gold standard through various experiments, suggesting that these technologies could be commercialised by providing real validation data in the near future. For example, from this table, STREMODO and PigInspector® are two technologies developed by two aWISH partners, whose objective is still working on the validation process to achieve a commercial use level in the future.

Table 16. List of sensors validated in a pig use.

Sensor name	Provider	Sensor type	Indicator	Status
SMARTBOW	Smartbow GmbH	Accelerometer	Activity level	On market
iDOL 65 camera	Dol sensors	Camera	Body condition	On market
FLIR One Pro LT	FLIR	Thermal camera	Body temperature	On market
SowSIS	ILVO + UGent	Load cells	Lameness	Prototype
TailTech	Innovent Technology Ltd	Camera	Tail position (tail biting)	Prototype
STREMODO	FBN	Microphone	Vocalisations	Prototype
PigInspector®	CLK GmbH	Camera	Ear lesions	Prototype
PigInspector®	CLK GmbH	Camera	Tail lesions	Prototype

The work and results obtained from tasks 2.2 and also task 2.1 provides a good understanding about which animal welfare indicators can be used to assess animal welfare issues at different stages of production. Furthermore, the research focused on obtaining the list of commercially available sensors and prototypes provides an overall view of the current market status and the lines of investigation. Most importantly, it is essential to underline the contribution of the respondents of the survey because, they contributed to expand the lists and have covered aspects of welfare assessed automatically that were not initially considered. Moreover, the survey has revealed the importance and the concern about validation, which is a fundamental aspect for aWISH scientific goals.

6. ANNEXES

6.1 Annex 1: Survey

Survey link access:
https://ec.europa.eu/eusurvey/runner/aWISH-TechonolgySurvey
Access to the file:
D2.2_Annex_1_aWISH_Survey.docx

6.2 Annex 2: Table of sensors used in pig production

Access to the excel file:
D2.2_Annex_2_aWISH_List_of_sensors_in_pigs.xlsx

6.3 Annex 3: Table of sensors used in broiler production

Access to the excel file:
D2.2_Annex_3_aWISH_List_of_sensors_in_broilers.xlsx

6.4 Annex 4: Table of survey results

Access to the excel file:
D2.2_Annex_4_aWISH-TechonolgySurvey_Results.xls

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